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Abstract: Rotary-wing aircraft (e.g., helicopters and tilt-wing aircraft) are an important component of all U.S. military services and the U.S. civil aviation industry. Our analyses of wildlife strikes to military rotary-wing aircraft, both within the United States and during overseas deployments, as well as civil helicopters, have shown there are important patterns within wildlife strike data for flight operations conducted on airfields and during off-airfield missions. Birds accounted for 93% of the wildlife strikes where the animal was identified, and mammals (primarily bats) accounted for 7%. Wildlife impacted all parts of civil helicopters and military rotary-wing aircraft during strike events; however, specific areas were impacted by wildlife with a higher frequency compared to others. We recommend airframe manufacturers and maintenance personnel consider reinforcing and redesigning rotary-wing aircraft windscreens and main rotor systems to better withstand the impact of wildlife.

Key words: airfields, civil aviation, military aircraft, rotary-wing, wildlife strikes

Helicopters comprise an important part of the general aviation industry in the United States (General Aviation Manufacturers Association 2013). In addition, rotary-wing aircraft (i.e., helicopters and tilt-wing aircraft) flight operations comprise essential mission components of all 4 military services within the U.S. Department of Defense and Department of Homeland Security, both in non-combat and combat situations. There are numerous hazards to helicopter flight safety, including physical hazards (e.g., wires, buildings, birds, trees), weather (e.g., wind, fog), and human factors (e.g., fatigue, loss of situational awareness) that result in damage to aircraft and human injuries and fatalities (Federal Aviation Administration 2000, Couch and Lindell 2010, U.S. Army 2012).

Wildlife collisions with aircraft (wildlife strikes) pose increasing safety risks and economic losses to civil aviation worldwide (Allan 2002, Thorpe 2010, DeVault et al. 2013). The flying services of the U.S. military also incur substantial losses from wildlife strikes (Zakrajsek and Bissonette 2005). Although wildlife strikes with both civil and military fixed-wing aircraft are well documented (Zakrajsek and Bissonette 2005, Dolbeer et al. 2013), the frequency, severity, and characteristics of wildlife strikes with helicopters are understudied. Recent efforts to understand wildlife strikes with civil helicopters (Washburn et al. 2013) and military rotary-wing aircraft (Washburn et al. 2014*a*,*b*) have provided insight into the species of wildlife involved and have identified temporal and spatial patterns of these events. However, other important characteristics of wildlife strikes with rotary-wing aircraft (e.g., damage rates, airframe models involved, impact locations on the aircraft) should be evaluated. The objectives of this project are to (1) conduct a comprehensive analysis of damage rate, airframe models, and impact locations (on the aircraft) associated with wildlife strikes to civil helicopters and U.S. military rotary-wing aircraft from all 4 military services, and (2) provide recommendations for reducing the frequency and negative impacts of wildlife strikes to rotary-wing flight operations.

Methods

Wildlife strike data for U.S. civilian helicopters are readily available from the Federal Aviation Administration's National Wildlife Strike Database (NWSD). We searched the NWSD and

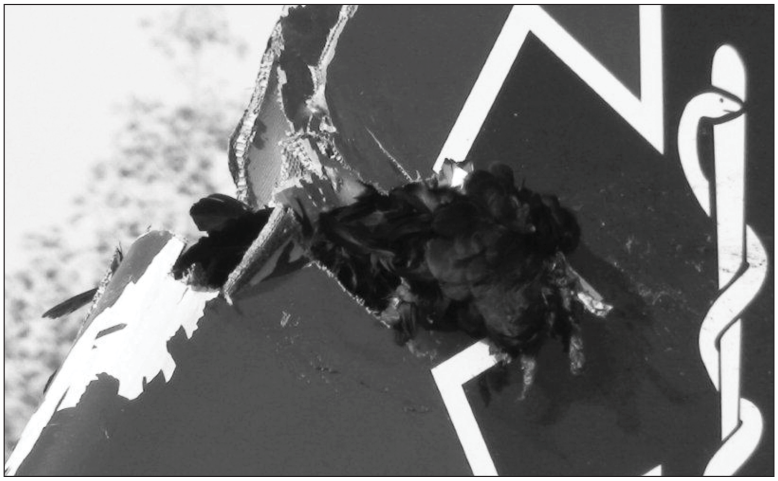

Figure 1. Wildlife strikes to helicopters involved all sections of the aircraft, including the tail section of this air ambulance. (*Photo courtesy of USDA Wildlife Services*)

extracted all records that involved helicopters during 1990–2011. The wildlife strike information in the NWSD is obtained through a voluntary reporting system; the information is primarily reported to the FAA by pilots and airports (Dolbeer et al. 2013).

We acquired all available wildlife strike records to U.S. military rotary-wing aircraft from the 4 military services, including the U.S. Army during 1990–2011, U.S. Air Force during 1994–2011, U.S. Navy and U.S. Marine Corps during 2000–2011, and U.S. Coast Guard during 1979–2011. In addition, we acquired pilot comments and other information regarding wildlife strike events with civil helicopters and military rotary-wing aircraft. For our analyses, we considered a tilt-wing aircraft, such as the Bell-Boeing V-22 Osprey, as a rotary-wing aircraft (Eden 2004, Montgomery and Foster 2006).

Using all available records from each of the 5 wildlife strike databases, we created a new inclusive rotary-wing wildlife strike database. We conducted a line-by-line review of each wildlife strike record in this database to ensure data integrity and consistency. Due to the diverse nature of the data fields contained within the different databases, it was necessary to extract data from narrative records, accident reports, and incident information (e.g., pilot commentary). We removed duplicate records (e.g., when the same wildlife strike incident was found in the U.S. Air Force and FAA civil databases). We recoded or classified wildlife strike information to allow for consistency in terminology/categories among civil and military strike records.

We parsed our database to include wildlife strikes to civil helicopters and military rotary-wing aircraft that were reported to have occurred within the contiguous United States, Alaska, Hawaii, or near shore areas along the coasts (i.e., <16 km from the U.S. coastline). In addition, we were able to extract and include in our database pertinent wildlife strike records to U.S. Army and U.S. Air Force military rotary-wing aircraft engaged in flight operations during overseas deployments (i.e., outside of the United States) associated with U.S. military bases around the world. Notably, these flight operations were conducted during training exercises, peacekeeping operations, and in theater combat operations (i.e., within Iraq and Afghanistan).

For each strike event, the rotary-wing airframe model was determined from the designation provided for that aircraft within the strike record and associated reports. Several civil and military variants of a given airframe model might exist, all of which were placed into the same airframe model category. For example, the Sikorsky manufactured H-60 airframe is used by the U.S. Army (as the Black Hawk), by the U.S. Air Force (as the Pave Hawk), by the U.S. Navy (as the Seahawk), and by the U.S. Coast Guard (as the Jayhawk). Variants of the Bell manufactured H-57 airframe are used by the military (e.g., NAVY TH-57) and by civilian entities and private companies (e.g., Bell Ranger series).

We defined the impact location as the area(s) of the airframe that the wildlife struck during a reported wildlife strike event (Figure 1). For example, if a bird hit the nose, chin bubble, or other part of the very front of an aircraft, the impact location was categorized as radome/nose. If wildlife struck >1 location on the aircraft (e.g., windscreen and main rotor system), the impact location was categorized as multiple impact.

We defined a wildlife strike event as a damaging strike if there was any amount of

Table 1. Number of all reported and damaging wildlife strikes for civil helicopter aircraft in the United States (USA) during 1990–2011, for military rotary-wing aircraft from each military service in the USA during 1979–2011, and for U.S. Army (ARMY) and U.S. Air Force (USAF) rotary-wing aircraft during overseas flight operations during 1979–2011[a].

Category (Location)	No. of reported strikes	No. of reported damaging strikes	% damaging strikes
Civil (in USA)	1,044	367	35.2
ARMY[b] (in USA)	318	134	42.1
USAF (in USA)	1,071	41	3.9
NAVY (in USA)	845	103	12.2
USCG (in USA)	251	102	40.6
ARMY (overseas)	238	175	73.5
USAF (overseas)	463	30	6.5

[a] Wildlife strike data for U.S. Army rotary-wing aircraft encompassed 1990–2011, for U.S. Air Force aircraft encompassed 1994–2011, for U.S. Navy and U.S. Marine Corps (combined) aircraft encompassed 2000–2011, and for U.S. Coast Guard rotary-wing aircraft encompassed 1979–2011.
[b] ARMY refers to rotary-wing aircraft from the U.S. Army, USAF refers to rotary-wing aircraft from the U.S. Air Force, NAVY refers to rotary-wing aircraft from the U.S. Navy and the U.S. Marine Corps, and USCG refers to rotary-wing aircraft from the U.S. Coast Guard.

damage to the aircraft reported. Damaging wildlife strikes varied greatly in the amount of actual damage incurred to the aircraft during the event, and ranged from minor abrasions found on the airframe or an aircraft component to the complete destruction of the aircraft.

Previous studies with fixed-wing aircraft clearly show differences in the patterns of bird strikes that occur within the airport environment and those that occur while the aircraft are traveling away from the airfield (Dolbeer 2006, Dolbeer 2011). For each strike record, the reported location of the strike event (if known) was determined to be on-airfield if the aircraft was within the horizontal boundary of an airfield when the strike occurred. Off-airfield strikes were defined as wildlife strike events that were reported to have occurred when the aircraft was not on an airfield or flying over an airfield (e.g., an aircraft en route to a specified destination). The U.S. Coast Guard wildlife strike database did not contain sufficient information to allow for this determination.

Many wildlife strike reports for civil helicopters and military rotary-wing aircraft were incomplete, and specific fields of information were missing, unknown, or we were unable to effectively obtain the information for report narratives; thus, sample sizes varied among individual variables and among specific analyses.

We obtained flight information (i.e., total number of flight hours) for each of the 4 rotary-wing airframes flown by the U.S. Air Force during 1994–2011. Unfortunately, the distribution of flight hours by airframe was not available for the other military services or civil helicopters.

Statistical analyses

Our investigation included identification of patterns in wildlife strikes with civil helicopters and military rotary-wing aircraft with respect to a variety of factors (e.g., impact location on the aircraft, whether the strike occurred on or off an airfield). We summarized wildlife strike data for civil helicopters and for each military service for flight operations within the U.S. as well as for U.S. Army and U.S. Air Force overseas flight operations.

We compared the proportion of damaging wildlife strikes relative to all wildlife strikes among the 4 military services using comparison of proportion tests (Zar 1996). Descriptive statistics were used to quantify the frequency of wildlife strikes that occurred to various airframe models. We used chi-squared analysis

Figure 2. Damage to helicopter windscreens occur when wildlife, such as this bald eagle (*Haliaeetus leucocephalus*), collide with aircraft during flight. (*Photo courtesy of Chris Cooper*)

(Zar 1996) to compare the number of wildlife strikes among various impact locations on the aircraft for civil helicopters and rotary-wing aircraft from each of the 4 military services (separately).

Using the total flight hours for each airframe flown by the U.S. Air Force and the total number of reported wildlife strikes for each airframe, we calculated an expected number of wildlife strike events per airframe. We used chi-squared analysis (Zar 1996) to determine if the observed number of reported wildlife strikes for each airframe was independent of the expected number of strikes (based on flight hours).

In addition, we summarized wildlife strikes that occurred within airport environments (i.e., on or over an airfield) and during flight operations off airfield separately. We used chi-squared analysis (Zar 1996) to compare the number of wildlife strikes among various impact locations on the aircraft for civil helicopters and rotary-wing aircraft from each of the 4 military services for on-airfield and off-airfield strike events (independently).

Results

We found 1,044 wildlife strikes with civil helicopters in the NWSD that occurred within the United States during 1990–2011 (Washburn et al. 2013). These helicopters were from a variety of public and private organizations, including U.S. federal government agencies (e.g., Department of Homeland Security), private companies (e.g., Rocky Mountain Helicopters), medical and emergency services, and owned by private citizens. We found 2,511 reported wildlife strikes with military rotary wing aircraft during flight operations within the United States during 1979–2011 (Table 1; Washburn et al. 2014*a*). Of these events, 318 wildlife strikes involved U.S. Army aircraft, 845 involved U.S. Navy, 1,071 involved U.S. Air Force aircraft, and 251 involved U.S. Coast Guard rotary-wing aircraft. We found 701 reported wildlife strikes with U.S. Army and U.S. Air Force rotary-wing aircraft during flight operations outside of the United States during 1990–2011 (Table 1; Washburn et al. 2014*b*).

Among the 4,256 wildlife strikes with rotary-wing aircraft found within our inclusive database, 1,442 of these records contained information regarding the taxa or group of wildlife involved. Birds accounted for over 93% of these wildlife strikes, whereas mammals (primarily bats) accounted for 7%.

Wildlife strikes that caused damage

Approximately one-third (35%) of the

reported wildlife strikes to civil helicopters resulted in damage to the aircraft (Table 1; Figure 2). Interestingly, the proportion of strikes with damage was 49% (ranging from 31% to 77% each year) in the years (1990–2008) prior to the ditching of US Airways 1549 into the Hudson River in January of 2009 (Marra et al. 2009). In the first 3 years after this incident (2009–2011), the proportion of damaging strikes decreased to 22% (ranging from 19% to 27% each year). Among the U.S. military services, the proportion of damaging strikes for U.S. Army (56%) and U.S. Coast Guard (41%) rotary-wing aircraft was higher (all $z > 62.9$, $P < 0.0001$) than for U.S. Air Force (5%) and U.S. Navy (12%) aircraft (Table 1).

Airframe models

Most of the civil helicopter strike records (98%) and all military rotary-wing strike records (100%) contained information regarding the airframe model of the aircraft struck (Table 2). Overall, the H-60 airframe accounted for the highest number of wildlife strikes to rotary-wing aircraft, representing over one-third (37%) of reported wildlife strikes. The H-57 and H-1 airframes accounted for 18% and 11% of all strikes, respectively, whereas all other airframes accounted for less than 10% each (Table 2).

Almost half (46%) of wildlife strikes to civil helicopters involved H-57 airframes, whereas 22% and 11% of strikes were to H-72 and H-68 airframes, respectively. All other civil helicopter airframes accounted for less than 10% of strikes (each).

Among military rotary-wing strike records, the H-60 airframe accounted for the highest number of wildlife strikes: specifically 41%, 58%, and 46% of the U.S. Army, U.S. Air Force, and U.S. Navy strikes, respectively. In contrast, 68% of the reported wildlife strikes to U.S. Coast Guard aircraft were to H-65 airframes. Tilt-wing aircraft (i.e., V-22) accounted for only 3% of all reported wildlife strikes to military aircraft (Table 2).

When examining U.S. Air Force rotary-wing aircraft, we found that the H-60 airframe experienced more wildlife strikes and the H-1 airframe experienced less wildlife strikes than expected ($\chi^2 = 118.6$, df = 3, $P < 0.0001$) based on the flight hours for each airframe. The number of reported wildlife strikes to the H-53 and V-22 airframes were approximately what would be expected based on the flight hours flown for those airframes.

Impact location on aircraft

Wildlife strikes impacted all parts of civil helicopters and military rotary-wing aircraft; however, specific areas were impacted by wildlife with a much higher frequency compared to others. The number of wildlife strikes varied across different parts of the aircraft ($\chi^2 = 620.3$, df = 9, $P < 0.0001$) for civil helicopters. The highest proportions of impact locations for these strikes were the windscreen and multiple locations on the aircraft (Figure 3).

During flight operations within the United States, the number of reported wildlife strikes to different sections of military rotary-wing aircraft (all 4 military services combined) varied ($\chi^2 = 676.5$, df = 9, $P < 0.0001$). Similarly, the frequency of wildlife strikes to sections of U.S. Army and U.S. Air Force (combined) rotary-wing aircraft conducting overseas flight operations varied ($\chi^2 = 157.0$, df = 9, $P < 0.0001$). Although the windscreen was the most frequently struck location on military aircraft during both flight operations within the United States and overseas, the main rotor system, radome/nose, and fuselage were also commonly impacted during strike events (Figure 3).

Damaging on-airfield wildlife strikes

When only on-airfield damaging strikes are considered, the frequency of wildlife strikes was similar ($\chi^2 = 8.0$, df = 9, $P = 0.53$) among the various locations on civil helicopters. However, half of the reported strike events for on-airfield strikes to civil helicopters involved an impact and consequently damage to the aircraft's main rotor system (Table 3).

The number of wildlife strikes varied among locations on military rotary-wing aircraft from the U.S. Army ($\chi^2 = 23.2$, df = 9, $P = 0.006$), but not for U.S. Air Force ($\chi^2 = 5.0$, df = 9, $P = 0.84$) and U.S. Navy ($\chi^2 = 15.1$, df = 9, $P = 0.09$) rotary-wing aircraft during on-airfield flight operations. Windscreens and main rotor systems were the most frequently impacted and damaged locations on U.S. Army and U.S. Navy aircraft (Table 3), whereas the fuselage, engine, and

Table 2. Number of reported wildlife strikes, by airframe model, for civil helicopters during 1990–2011 and for U.S. military rotary-wing aircraft from each military service during 1979–2011[a].

Airframe model	Civil	ARMY[b]	USAF[b]	NAVY[b]	USCG[b]	Total
H-1	16	78	328	34	-	456
H-3	-	-	-	18	47	65
H-6	66	14	-	-	-	80
H-13	2	-	-	-	-	2
H-46	-	-	-	31	-	31
H-47	-	38	-	-	-	38
H-53	-	-	292	25	-	317
H-55	79	-	-	-	-	79
H-57	475	-	-	282	-	757
H-58	-	74	-	-	-	74
H-60	26	225	888	390	41	1,570
H-64	-	107	-	-	-	107
H-65	27	-	-	-	187	214
H-67	-	18	-	-	-	18
H-68	112	-	-	-	2	114
H-72	222	-	-	-	-	222
V-22	-	-	25	65	-	90
Other	-	2	1	-	-	3

[a] Wildlife strike data for civil helicopters encompassed 1990−2011, for U.S. Army rotary-wing aircraft encompassed 1990−2011, for U.S. Air Force aircraft encompassed 1994−2011, for U.S. Navy and U.S. Marine Corps (combined) aircraft encompassed 2000−2011, and for U.S. Coast Guard rotary-wing aircraft encompassed 1979−2011.
[b] ARMY refers to rotary-wing aircraft from the U.S. Army, USAF refers to rotary-wing aircraft from the U.S. Air Force, NAVY refers to rotary-wing aircraft from the U.S. Navy and the U.S. Marine Corps, and USCG refers to rotary-wing aircraft from the U.S. Coast Guard.

radome/nose were the most frequently struck and damaged parts of U.S. Air Force aircraft (Table 3).

Damaging off-airfield wildlife strikes

When only off-airfield damaging strikes are considered, the number of wildlife strikes varied ($\chi^2 = 242.3$, df = 9, $P < 0.0001$) among the locations on civil helicopters. Windscreens and multiple impact locations were the most frequently impacted and damaged parts of civil helicopters during off-airfield strike events (Table 3).

Windscreens and main rotor systems were the most frequently struck and damaged parts of U.S. Army rotary-wing aircraft during off-airfield flight operations ($\chi^2 = 119.0$, df = 9, $P < 0.0001$; Table 3). The number of damaging strikes to different sections of the aircraft also varied for U.S. Navy ($\chi^2 = 24.3$, df = 9, $P = 0.004$), but not U.S. Air Force ($\chi^2 = 9.7$, df = 9, $P = 0.38$) aircraft. Almost half (48%) of off-airfield damaging strikes to U.S. Navy aircraft involved the aircraft windscreen (Table 3). Although the fuselage was the most frequently struck and damaged part, all areas of U.S. Air Force rotary-wing aircraft were struck and damaged during off-airfield flight operations (Table 3).

Discussion

Wildlife strikes with civil and military helicopters represent an important flight safety concern within the United States and throughout the world. Damage to rotary-wing aircraft frequently occurs during wildlife strikes, and the potential for human injuries and fatalities is notable. We found patterns in wildlife strike damage rates, airframes involved, and impact locations on aircraft among wildlife strike reports for civil helicopters and military rotary-wing aircraft.

The percentage of reported damaging wildlife strikes to U.S. Army and U.S. Coast Guard rotary-wing aircraft was much higher than to U.S. Air Force and U.S. Navy aircraft. We believe that wildlife strikes to U.S. Army and U.S. Coast Guard aircraft typically are being reported more frequently when monetary damage occurs to the aircraft. In contrast, it would appear a much higher proportion of non-damaging wildlife strikes to U.S. Air Force and U.S. Navy rotary-wing aircraft are being reported. Furthermore, there was no information (and apparently no protocols) for identifying the wildlife species involved in wildlife strike events to U.S. Army and U.S. Coast Guard aircraft. Such information is critical to understanding and alleviating the risk of wildlife strikes to military aircraft (Dolbeer et al. 2013).

Several factors likely influence the frequency of wildlife strikes to the various rotary-wing airframes. Although some airframes are found in the civilian fleet as well as used by all 4 military services (e.g., H-60), others are flown only in the civilian fleet (e.g., H-72) or by only 1 military service (e.g., H-46, H-47). Also, the number of specific airframes flown by an individual military service varied over time (e.g., the number of H-65 airframes within the U.S. Coast Guard has increased during recent years). Wildlife strike rates to specific airframes are also influenced by the specific mission (and consequently the flying environments) of the aircraft. For example, the U.S. Air Force uses the H-60 airframe for search and rescue operations

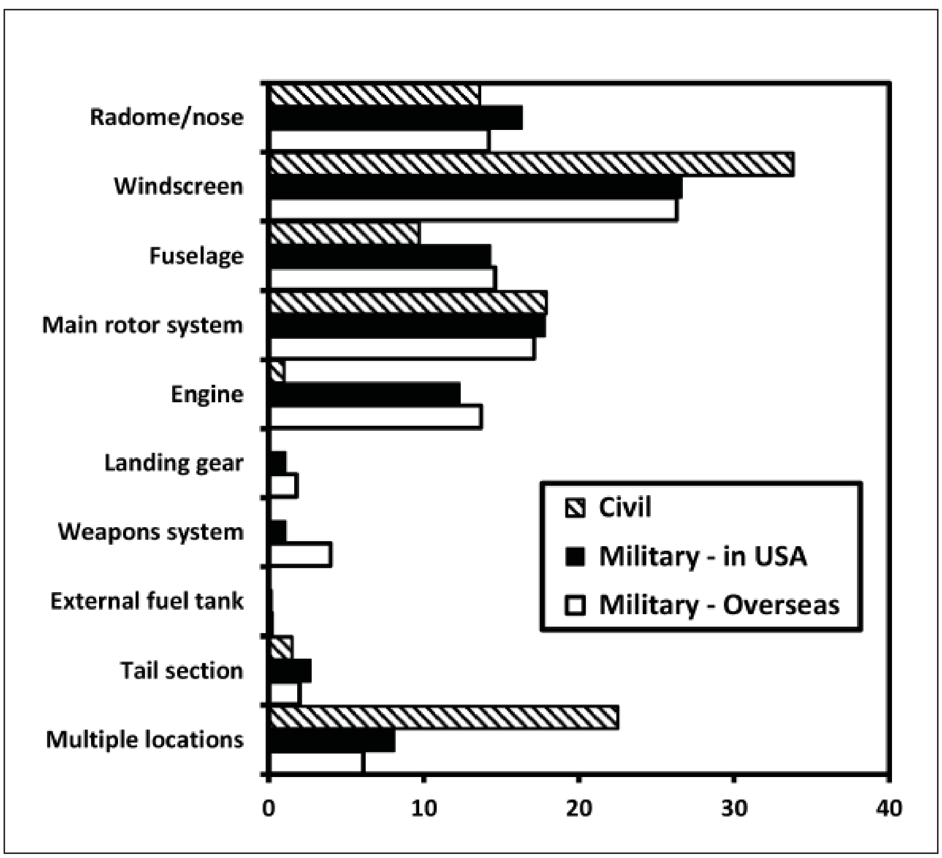

Figure 3. Proportion (%) of reported wildlife strikes, by impact location on the aircraft, in the United States (USA) for civil helicopters during 1990−2011, U.S. military rotary-wing aircraft (all services combined) for flight operations within the USA during 1979−2011, and for U.S. Army and U.S. Air Force rotary-wing aircraft (combined) for overseas flight operations during 1990−2011.

Table 3. Proportion (%) of all damaging wildlife strikes, by impact location on the aircraft, when the aircraft was reported as being on-airfield and off-airfield for civil helicopters during 1990–2011, U.S. Army rotary-wing aircraft during 1990–2011, for U.S. Air Force aircraft during 1994–2011, for U.S. Navy and U.S. Marine Corps (combined) aircraft during 2000–2011.

Impact location	Civil		ARMY[a]		USAF		NAVY	
	On-airfield	Off-airfield	On-airfield	Off-airfield	On-airfield	Off-airfield	On-airfield	Off-airfield
Radome/nose	10.0	16.0	13.7	17.1	11.1	17.9	5.6	10.9
Windscreen	10.0	37.6	27.5	31.4	11.1	7.1	38.9	47.8
Fuselage	10.0	7.1	5.9	7.8	22.2	25.0	11.1	6.5
Main rotor system	50.0	6.2	23.5	20.2	11.1	10.7	33.3	8.7
Engine	0.0	1.1	18.8	7.8	22.2	14.3	0.0	10.9
Landing gear	0.0	0.0	0.0	0.0	0.0	3.6	0.0	2.2
Weapons system	0.0	0.0	0.0	1.9	0.0	7.1	0.0	0.0
External fuel tank	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2
Tail section	0.0	1.8	9.8	3.1	22.2	4.3	0.0	2.2
Multiple locations	20.0	30.2	7.8	10.9	0.0	0.0	11.1	8.7

[a] ARMY refers to rotary-wing aircraft from the U.S. Army, USAF refers to rotary wing aircraft from the U.S. Air Force, and NAVY refers to rotary-wing aircraft from the U.S. Navy and the U.S. Marine Corps.

and the H-1 airframe for combat operations.

Wildlife strikes occurred and damaged various sections of the aircraft in unequal proportion. Forward sections of the aircraft (e.g., windscreen and radome/nose) and the main rotor section (a large section of the aircraft in regard to surface area and movement) were struck and damaged by wildlife with a much higher frequency than the rest of the airframe. This finding was expected, as a bird(s) flying toward the aircraft (and vice versa) would encounter the front of the aircraft first. Similarly, the large size of the rotating rotor blades would intercept wildlife that was diving (e.g., dropping in altitude) or passing by the fuselage/airframe itself. In contrast, wildlife that approaches the aircraft from below or from the side would have the potential to impact other parts of the airframe (e.g., tail section, fuselage). Further investigations into the behavioral responses of wildlife to rotary-wing aircraft is an interesting and important area for future research (Blackwell et al. 2009, Blackwell et al. 2012).

Overall, wildlife strikes with civil helicopters and military rotary-wing aircraft were generally similar. Damaging wildlife strikes occurred more frequently off-airfield for both civil helicopters and military rotary-wing aircraft, but on-airfield wildlife strike events were also important. Increasing pilot awareness and understanding of the potential for wildlife strikes during off-airfield flight operations, thus increasing vigilance for wildlife and other physical hazards (e.g., wires, trees), is essential for reducing the frequency and damage associated with off-airfield accidents and collisions. Integrated wildlife damage management programs to reduce the presence of hazardous wildlife within airport environments are important for reducing the risk of on-airfield wildlife strikes (DeVault et al. 2013).

The windscreen and main rotor system were the most commonly struck and damaged areas of both civil helicopters and military rotary-wing aircraft, but reports of impacts to multiple locations on the aircraft were more common for civil helicopters. We recommend airframe manufacturers and maintenance personnel consider reinforcing and redesigning rotary-wing aircraft windscreens and main rotor systems to better withstand the impact of wildlife. These modifications could greatly reduce the damage and human injuries associated with wildlife strikes.

Management implications

Wildlife strikes to civil helicopters and military rotary-wing aircraft often result in damage to the aircraft and represent a serious flight safety issue. Proper reporting of all wildlife strikes, in particular those that do not result in aircraft damage, is important to provide information useful for understanding and managing wildlife strikes to rotary-wing aircraft. Reinforcement and redesign of critical areas of rotary-wing aircraft, such as windscreens and main rotor systems, to better withstand the impact of wildlife (e.g., large birds) could greatly reduce the damage and human injuries associated with wildlife strikes to civil helicopters and military rotary-wing aircraft.

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